STRUCTURE AND COMPOSITION OF VEGETATION OF LONGLEAF PINE PLANTATIONS COMPARED TO NATURAL STANDS OCCURRING ALONG AN ENVIRONMENTAL GRADIENT AT THE SAVANNAH RIVER SITE

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Abstract—Fifty-four plots in 33-43 year old longleaf pine plantations were compared to 30 remnant plots in longleaf stands on the Savannah River Site in South Carolina. Within these stands, the structure and composition of primarily the herb layer relative to a presumed soil moisture or soil texture gradient was studied using the North Carolina Vegetation Survey methodology. Data were also collected on soils and landform variables. Based on ordination and cluster analyses, both plantation plots and natural stand plots were separated into three distinct site units (xeric, sub-xeric, and sub-mesic). The plantation plots had an overall classification rate of 78 percent while the natural plot classification rate was 87 percent. The xeric end of the gradient demonstrated the most similarity between the remnant and plantation plots. Among all the plots, presence or absence of a B horizon was the most discriminating environmental factor. On the plantation sites, 265 species were found as compared to 297 species on the remnant natural sites. Overall species richness was significantly greater on the remnant sites with a mean of 74.00 species per 0.1 hectare compared to 57.11 for the plantation sites. However, of the 265 species found on plantation sites, roughly 90 percent were judged to be representative of natural or native longleaf pine communities. This lack of a major compositional difference between xeric plantation and natural longleaf sites suggests that restoration of the herbaceous layer may not be as complex as once thought. This provides reasonable encouragement for the restoration of the longleaf pine ecosystem.

INTRODUCTION

The decline of the longleaf pine ecosystem has been well documented. Longleaf pine once dominated as much as 92 million acres throughout the Southeastern United States (Frost 1993). This natural range covered most of the Atlantic and Gulf Coastal Plain regions, from southeastern Virginia to eastern Texas and south into the northern two-thirds of Florida, with extensions into the Piedmont and mountains of northern Alabama and northwest Georgia (Landers and others 1995). Recent estimates show that there may be as little as 3.2 million acres of natural longleaf pine left (USDA Forest Service, Forest Inventory and Analysis, unpubl. data). For this reason, there has been an increase in the efforts to sustain the natural longleaf stands that remain and to restore these ecosystems on a portion of the sites from which they have been extirpated (Mitchell and others 1997).

There is a growing interest in the structure and composition of pine plantations and how they compare to natural longleaf stands. This information is needed to assess the potential for restoration and to develop protocols for restoration. Information about the distribution of longleaf pine communities along environmental gradients (e.g. Christensen 1988, Harcombe and others 1993, Peet and Allard 1993, Jones and others 1984) is available, but little has been published regarding the composition and structure of plantations relative to the same environmental gradients.

This study describes current vegetation patterns and relationships on disturbed plantation sites and compares them to natural, or relatively undisturbed, longleaf pine stands at the Savannah River Site. Sample sites were mostly pine dominated upland sites. Keeping in mind that the ultimate management goal of these plantation sites is restoration to their " natural" state, an understanding of the historical/natural ecosystem conditions, current conditions, and processes that affected the changes is required (Walker and Boyer 1993).

STUDY AREA

The Savannah River Site (SRS) is a 192,323-acre circular tract of federal land that occupies parts of Aiken, Barnwell, and Allendale Counties, South Carolina (Cooke 1936). It is located northeast of the Savannah River on the upper Atlantic Coastal Plain of South Carolina. The Savannah River Site (SRS) has three major geologic/ physiographic regions. These regions are the sandier, excessively drained and droughty areas called the Sandhills Region, the more productive sandy loams and loamy soils of the Upper Loam Hills Region, and the more fertile, well-drained soils of the Red Hills Region (Myers and others 1986). Present vegetation at the SRS largely reflects past disturbance or manipulation by man and is distributed across a moisture gradient

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extending from xeric, droughty, deep sandy ridges to hydric, flooded marshes and swamps (Jones and others 1981, Van Lear and Jones 1987). These disturbed sites are old fields that were the result of intensive agriculture and subsequently replanted with pine, less intensive agricultural sites that were left to regenerate naturally, cutover forests that have had a continuous forest cover of scrub oak/pine, and areas where the natural fire regime has been altered or suppressed.

METHODS

Site Selection

Fifty-four plantation sites were selected at the SRS by using a predetermined set of criteria. Sites must have been (1) dominated by longleaf or slash pine only, (2) planted between 1955 and 1965, (3) located on one of three different soil moisture classes, and (4) burned at least once within the past five years. This method of site selection was accomplished through the use of Geographical Information System (GIS) ARC/INFO software from the Savannah River Forest Service-GIS laboratory. Because too few longleaf pine plantations were available, slash pine plantations on sites originally dominated by longleaf pine were incorporated into this study to increase the sampling area. Because prior history and site preparation methods were similar, consistency between slash and longleaf ground vegetation was expected.

Thirty natural longleaf pine stands were located at the SRS using a variety of methods. First, candidate stands were identified in an inventory by Cecil Frost, Plant Ecologist, North Carolina Department of Agriculture. Additional plots were located using information from local botanists, ecologists, United States Forest Service personnel, GIS software, satellite imagery, digitized maps linked to databases, and reconnaissance work in the field to locate other suitable natural stands. Criteria used to help determine natural vegetation included, but were not limited to (1) observations of vegetation structure, by layer, under known fire regimes, (2) presence of remnant fire frequency indicator species, (3) presence of remnant fire frequency indicator communities, and (4) known historical records of remnant or natural areas (Frost 1997).

Field Sampling

Plot size for most North Carolina Vegetation Survey (NCVS) plots was 20 x 50 meters (1000m^2 or 0.1 hectare). An alternative configuration of 20 x 20 meter (400m^2) plots was used for sampling several of the natural longleaf stands. This alternative plot size was necessary due to the relatively small patches of natural longleaf pine scattered throughout the Savannah River Site. Using a smaller plot size (400m^2) was the only method available to ensure homogenous sampling of natural vegetation. This alternative plot size (400m^2) is within the size range recommended by Mueller-Dombois and Ellenberg (1974) for sampling forest vegetation. The widespread use of these NCVS plots in a variety of forested vegetation types and the consequent availability of substantial comparative vegetation data at this scale led to the adoption of these plot sizes.

The NCVS (Peet and others 1998) uses a modular approach for sampling. Within each 0.1 ha (1000 m^2) plot, there was a 2 x 5 array of 10 x 10m modules (100 m^2 or 0.01 hectare). Within this 2 x 5 array of modules, there was a prescribed block of four focal modules (in a 2 x 2 array). The focal modules were intensively sampled. An aggregate count of woody stems was made in the remaining six modules, and this area (600 m^2) was searched for species not encountered in the four focal modules measured previously. In the alternative configuration of 400m^2 plots, all four modules were treated as focal modules and intensively sampled according to NCVS methodology.

Soil samples for chemical analysis were collected in the center of each of the focal. For each sample a core of mineral soil to a depth of 10 cm was collected for chemical analysis. Soil samples for textural analysis were collected in the middle of the plot along the midline. A sample of the A and B or C horizon was collected and depth to maximum clay and depth of litter layer recorded. The soil series and a description of the soil profile were also recorded. Soil samples were analyzed by Brookside Labs (308 S. Main St., Knoxville, OH 45781).

Data Analysis

A series of multivariate techniques was used for data analysis. Detrended Correspondence Analysis (DCA) (DECORANA, Hill 1979a), was on used to analyze vegetation data (McCune and Mefford 1999). DCA or DECORANA© is an ordination program that ultimately displays stand and/or species data in multidimensional space (Hill 1979a). The distance between stands or species indicates the relative degree of similarity or difference (Hutto and others 1999).

Cluster analysis of vegetation was performed by Two Way Indicator Species Analysis (TWINSPAN, Hill 1979b). TWINSPAN© is a polythetic diverse classification that simultaneously classifies both species and plots using the main matrix for vegetation data (McCune and Mefford 1999). TWINSPAN was used in conjunction with DCA to reduce this subjectivity in delineating groups of similar plots. TWINSPAN was also used to identify indicator or diagnostic species that were strongly correlated to a certain community association.

Stepwise discriminant analysis and discriminant analysis techniques were used to identify those environmental variables which best described the stands which had already been placed into groups by ordination and classification(Afifi and Clark 1990). Soil and landform variables were used in the analysis. Stepwise discriminant analysis was used to determine which of these variables were significant at the 0.15 and 0.20 level of significance for plantations and natural sites respectively. Discriminant analysis was then used to accurately predict site unit membership using the discriminating environmental variables that were identified for both plantation and natural stands.

Standardized t-tests at the 0.05 level of significance were used to test for significant differences between plantations and natural stands. Mean environmental and physical

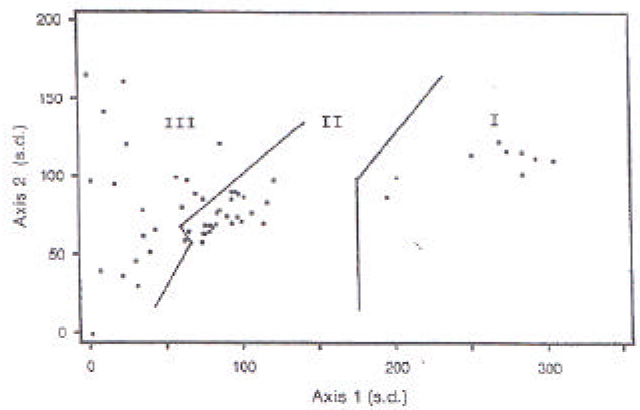

Figure 1—Ordination of 54 plantation plots using full importance values.

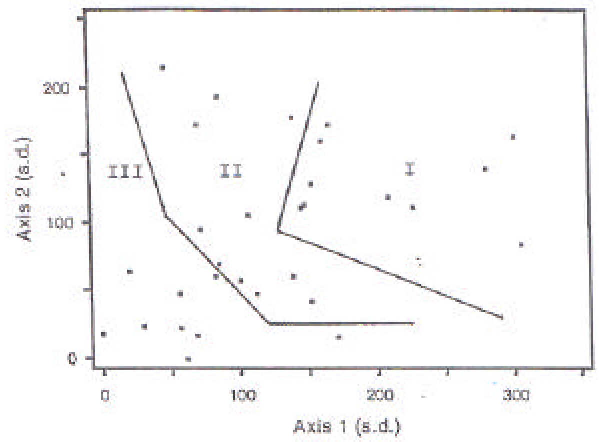

Figure 2—Ordination of 30 natural plots using full importance values.

variables as well as species abundances were tested for significant differences between plantation and natural sites occurring on similar soil moistures.

RESULTS

Plantation Sites

The primary data matrix for plantation sites consisted of 54 plots and 265 species. The ordination Axis 1 was related to a soil moisture gradient (figure 1). Based on ordination and cluster analysis, the plots were separated into three groups. Plots near the origin of the graph exist on the extreme xeric end of the soil moisture gradient, while plots near the end of the graph exist on the more mesic end of the gradient. Groups were labeled I, II, and III, with I on the mesic and III on the xeric end of the gradient. There was also some variation among plots on the xeric end of Axis 2. The source of this variation has not been determined, and is most likely the result of some disturbance due to previous land use.

Of the fifteen environmental variables used in stepwise discriminant analysis, three significant variables were found at the 0.15 level of significance for plantations. These variables were (1) presence/absence of B horizon, (2) soil pH, and (3) percent sand in B or C horizon.

Discriminant function analysis determined the classification success rate for each ecological site unit or group. The resubstitution success rate was 81 percent and misclassified a total of eight plots. The cross-validation success rate was 78 percent and misclassified nine plots.

TWINSPAN was used to find indicator species for each group of plantation sites identified. Generally, an indicator species is a species of narrow ecological amplitude with respect to one or more environmental factors (Allaby 1994). For this study, indicator species are defined more loosely as the most characteristic community members and include species typical of and vigorous in a particular environment. Indicator species for group I sites included *Pinus elliottii*, *Pinus taeda*, and *Chimaphila maculata*. Indicators of group II sites included *Dichanthelium commutatum*, *Desmodium vridiflorum*, and *Centrosema virginianum*. *Quercus laevis*, *Quercus incana*, and *Bonamia patens* were indicators of group III sites.

Natural Stands

The primary data matrix for natural stands consisted of 30 plots and 297 species. Ordination arranged these plots along a soil moisture gradient (axis 1) that showed a beta diversity of 3.5 standard deviations (figure 2). Based on ordination and cluster analysis, these plots were separated into three groups, with plots (group III) near the origin of the graph on the extreme xeric end of the gradient, and plots (group I) near the end of the graph on the more mesic end of the gradient. Axis 2 showed a beta diversity of 2.5 standard deviations.

Of the fifteen environmental variables used in discriminant analysis, eleven were found to be significant at the 0.20 level of significance. These variables were (1) presence/absence of B horizon, (2) landform index, (3) soil magnesium, (4) sodium, (5) calcium, (6) nitrogen, and (7) potassium, (8) organic matter, (9) percent sand in respective horizon, (10) percent clay in the respective horizon, and (11) percent sand in the A horizon.

Discriminant function analysis was then performed to find classification success rates for each ecological site unit or group. The resubstitution success rate was 100 percent. The cross-validation success rate was 87 percent with four plots missclassified.

Each group of natural stands defined by ordination/classification revealed a distinguishable group of vegetation and set of associated physical and environmental variables. TWINSPAN was used to find indicator species for each group of natural stands identified. Iindicators of group I sites include *Quercus stellata*, *Aristolochia serpentaria*, and *Clitoria mariana*. Group II indicators included *Aristida beyrechiana* and *Pinus taeda*. *Opuntia compressa*, *Cnidoscolus stimulosus*, and *Cirsium repandum* were indicators of group III sites.

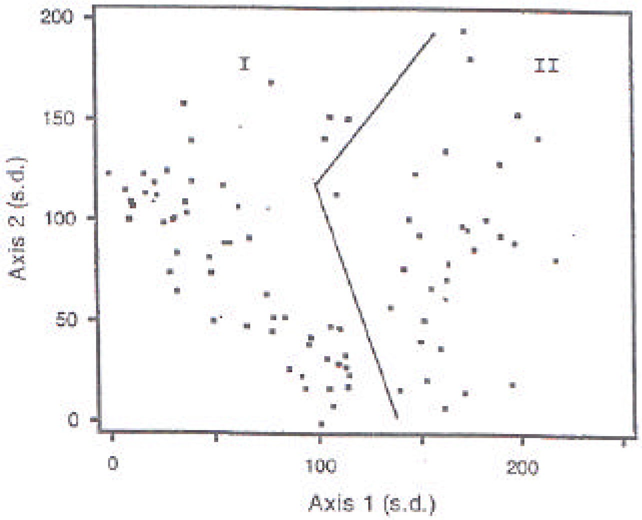

Figure 3—Initial ordination of both plantation and natural plots (n = 84) using species presence/absence values and first order division.

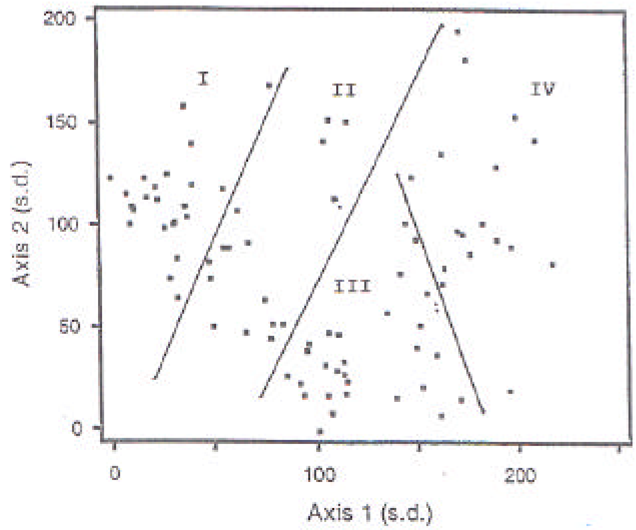

Figure 4—Ordination of both plantation and natural plots (n = 84) using species presence/absence values and second order division.

Plantation Sites Versus Natural Stands

The primary data matrix for both plantations and natural stands consisted of 84 plots and 361 species. Ordination separated all eighty-four plots into two groups (figure 3). These groups corresponded to the first order division of TWINSPAN. Plots were separated into two distinct associations based on origin (plantation or natural). Ordination arranged each of these groups along a distinct soil moisture gradient (axis 1) that showed an overall beta diversity of 2.5 standard deviations. Group I plots were identified as plantation sites and arranged along a soil moisture gradient that has a beta diversity of 1.5 standard deviations. Plots near the origin of the graph exist on the mesic end of the soil moisture gradient, while plots near the center of the graph exist on the xeric end of the gradient. Group II plots were identified as natural stands and arranged along a soil moisture gradient that showed a beta diversity of 1.0 standard deviations. Plots near the center of the graph exist on the xeric end of the soil moisture gradient, while plots near the end exist on the mesic end of the gradient.

The second order of division of TWINSPAN was used to further break down plot groupings. Plots were then separated into four groups (figure 4). These groups exist along the same presumed soil moisture gradients noted above. Groups were labeled I, II, III, and IV. Of the four groups identified, groups I and II were of plantation origin and IV was of natural origin. Group III was the only group of plots that displayed combination of plantation and natural stands (figure 5). Group III occurred on the xeric end of the soil moisture gradient. This would suggest that on the most xeric sites, similar vegetation may exist on both plantation and natural stands. Group III was further divided by the third order of division. Group III_A identifies plots of plantation origin while group III_B identifies plots of natural origin.

Overall mean species richness of plantation sites ranged from a low of 53.44 species per 0.1 hectare on sub-mesic sites to a high of 60.73 species per 0.1 hectare on sub-xeric sites. Overall mean species richness of natural sites ranged from a low of 71.09 species per 0.1 hectare on sub-xeric sites to a high of 76.33 species per 0.1 hectare on xeric sites. The species richness across all natural stands was found to be significantly higher compared to plantations (74.00 versus 57.11 species per plot; t-test, alpha <0.1).

CONCLUSIONS

Three distinct vegetative communities were described for both longleaf plantation and natural sites across a soil moisture gradient at the Savannah River Site. Presence/absence of the B horizon, soil pH, and percent sand in the underlying soil horizons (B or C) were the most discriminating environmental variables separating plant communities on longleaf plantation sites. On natural stands, eleven discriminating variables were used to separate plant communities: the presence/absence of the B horizon, landform index, levels of soil magnesium, sodium, calcium, nitrogen, potassium, and organic matter, and percent sand in respective horizon (A, B, and C horizons). Variables controlling the distribution of vegetation among natural groups are not as clearly defined as plantation groups. The presence or absence of a B horizon was the most discriminating environmental variable discriminating among groups for both plantation and natural stands.

Plots were separated into two distinct associations based on origin (plantation or natural). Further, the most similar groups of plots between plantation and natural stands were those that occurred on the most extreme xeric end of the soil moisture gradient. Although overall species richness was significantly higher on natural stands, vegetation composition and structure on these sites were most similar for both xeric plantations and natural stands. This work suggests that well-burned xeric longleaf plantations that have

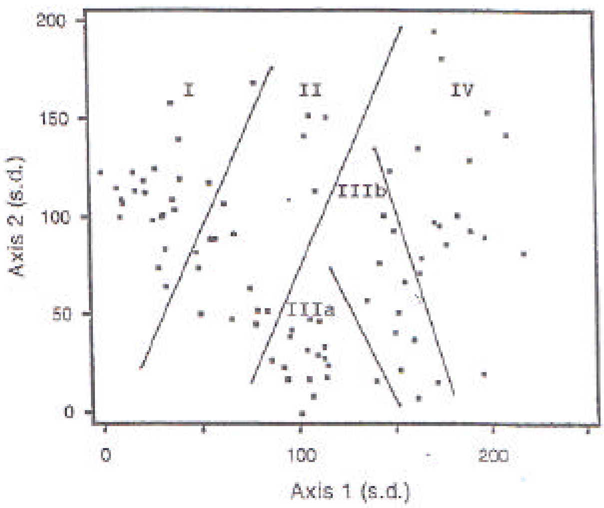

Figure 5—Final ordination of both plantation and natural plots (n = 84) using species presence/absence values.

undergone limited soil disturbance may not be as degraded as previously thought (Noss 1989; Abrahamson and Hartnett 1990).

Out of the 265 species found on plantation sites sampled, about 90 percent were judged to be species representative of natural or native longleaf pine sites. The lack of compositional differences between xeric plantation and natural stands suggests that restoration of the herbaceous layer of longleaf plantations may not be as complex as often thought. Restoration of plantation sites may require the reintroduction of only several native species to the landscape, as well as management practices best suited to maintain natural conditions, such as frequent burning and thinning of the canopy to restore herb vigor.

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